Determination of the Temperature Coefficient, and Coefficient of Resistivity Of Copper, Iron and Aluminum

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Determination of the
temperature coefficient,

DETERMINATION OF THE TEMPERATURE COEFFICIENT, AND COEFFICIENT OF RESISTIVITY OF COPPER, IRON AND ALUMINUM

A THESIS

PRESENTED BY

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[illegible]

[illegible]

L. C. Monin

Dean of Cultural Studies

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DETERMINATION OF TEMPERATURE COEFFICIENT AND COEFFICIENT OF RESISTIVITY OF COPPER, IRON, AND ALUMINIUM.

The object of the following experiments was to find the mean temperature coefficient, α, between the temperatures of 0° and 100° Centigrade, in the formula

$$R_t = R_o(1 + \alpha t)$$

in which R_o is the resistance of a conductor at 0° C. and R_t at t° C.; also the mil-foot resistance, and the volume and mass resistivity of various samples of copper, iron and aluminium.

The temperature coefficient, α, is defined to be the increase in resistance of a conductor per degree per ohm resistance at 0° C. The mil-foot resistance of a conductor is the resistance of a conductor one foot long and one circular mil in cross sectional area. The volume resistivity of any material is defined to be the resistance of a cube of the material one centimeter on a side. The usual manner of stating this resistivity is in michroms per centimeter cube at 0° C. To determine the volume resistivity of a sample of a metal or alloy, it is desirable to possess it in the form of a carefully drawn wire of uniform circular cross section. Owing to the difficulty of determining the diameter of very fine wires, it is found more desirable and convenient to determine and define the resistivity of metals and alloys by the resistance in ohms per meter gramme at 0° C., that is to say, by stating the ohmic resistance at 0° C. of a wire of circular cross section having a length of one meter and weighing one gramme.

This is known as the mass resistivity.

The samples tested were copper, steel and aluminium wires as follows:

Sample 1. #10 B.&S. gauge, annealed copper wire obtained from John A. Roebling's Sons Co.

Sample 3. #14 B.& S. gauge annealed copper wire.

Sample 4. #14 B.& S gauge annealed copper wire.

Sample 5. #14 B.& S. gauge annealed copper wire.

Sample 6. #14 B.& S. gauge annealed copper wire.

Sample 9. # 8 B.& S. gauge annealed copper wire, obtained from the Okanite Co.

Sample 10. # 9 B.& S. gauge annealed copper wire, obtained from the American Steel & Wire Co.

Sample 2. # 8 B.W.G. steel wire, American Steel & Wire Co's Extra B.B.

Sample 7. Roebling's #8 B.B.

Sample 8. Roebling's #8 Extra B.B.

The three samples of steel were obtained through the courtesy of the Ristine Co.

Samples I and II of annealed Aluminium about #10 B.W.G. from the American Aluminium Co.

The resistances at various temperatures ranging from 0° to 100° C. were measured by means of the Thompson double bridge. A scheme of the bridge and the connections for the determination of the resistances is shown on an accompanying blue print. The principle of the bridge method is that of balancing the drop across the unknown resistance against the drop across a

known resistance, so that all the resistances of lead wires are eliminated. The wire to be tested was cut into samples twenty-two inches in length and a sample was placed in the box containing the oil bath for heating and fastened and held straight by means of the clamps, AA, (see photograph) which are connected to the series posts of the box. The wire was then connected in series with the known resistance, a Hartmann and Braun .001 ohm standard manganin resistance, and also in series with an ammeter, a carbon rheostat, a storage cell and a switch as shown in the scheme. The rheostat was adjusted so that a current of 15 amperes flowed through the series circuit. The heating box is so arranged that the knife edges, exactly 50 centimeters apart, rest upon the wire to be tested, between the series posts, so that the drop across 50 centimeters of the wire is balanced against the drop across the standard resistance. These knives, BB ,in the photograph, are connected by large copper leads to the pressure binding posts on the top of the box. These posts were connected to the posts marked, xx , on the bridge and also the pressure posts on the standard resistance were connected to the posts marked, NN , on the bridge. The galvanometer was also connected as shown in the scheme. The galvanometer used was a Leeds and Northrop, suspended coil type, mounted in a wall case on springs so that the jarring of the building would have a minimum effect in deflecting the coil. The deflection was read by means of a telescope and scale so as to obtain a maximum accuracy in the adjustment of the resistances

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on the bridge for a balance, the coil showing no deflection at this point.

To obtain temperatures above that of the room, the oil bath surrounding the wire was heated by an electric heating coil. Readings of resistance were taken about every five degree increments in temperature up to 100° C., the oil being constantly stirred both by hand and electric motor. At each temperature where the resistance was measured the heat was partly shut off, only enough being left on to keep the temperature constant, the amount of heating current left on being adjusted through a lamp rack. After the temperature had remained constant for a short time, the dials on the bridge were adjusted, the two 100 plugs, as shown in the photograph being out, until the galvanometer showed no deflection; the temperatures and resistances were then read simultaneously and recorded.

The temperatures below that of the room were obtained by running cold brine through a coil of tin piping in the oil bath. The arrangement for running the brine through the coil from a tank is shown in a photograph of the apparatus. On account of the high congealing point of the oil used for the high temperatures, kerosene was substituted for the low temperatures. In this way the temperature of the bath was reduced to 0° C., readings of resistance being taken as before.

The temperatures were read by means of two accurate thermometers, reading from 0° to 100° C., and graduated to tenths of a degree, placed in the oil through the top of the heating

box. The mean temperature of the wire for each reading was taken as the average between the two thermometer readings. This mean temperature was corrected for the mercury in the stem projecting above the oil in the box by means of the formula

$$T = t - .000143\ n\ (t' - t) \qquad \text{(Smithsonian Tables)}$$

in which T is the corrected temperature, t, the observed temperature, and t', the mean temperature of glass stem and mercury column; this temperature was assumed to be a little above room temperature; n is the length of the mercury column in the stem in scale degrees, this length being figured from the fifteen degree point, the mercury being subjected to the heat of the oil up to the fifteen degree mark. This correction amounts to about nine tenths of a degree at 100° C.

According to the certificate for the Hartmann and Braun standard resistance as tested by the Bureau of Standards, ~~its~~ its resistance at 20.4° C. is .00009846 international ohms. This value was used throughout as the resistance of the standard coil. If N is the reading on the dials of the bridge for a balance, then R, the resistance of fifty centimeters of the wire, is given by the equation

$$\frac{R}{.00009846} = \frac{N}{100} \qquad \text{or} \qquad R = N \times \frac{.00009846}{100}$$

when the two 100 plugs are out.

Curves were platted as shown on sheets 1 to 10 with temperature as abscissae and resistances as ordinates. From these curves, which were found to be straight lines, the everage temperature coefficient was obtained. The mean temperature coefficient was taken as the average coefficient figured from each of the pointswhich fell on the curves.

The mil-foot resistance for each sample was found at 0° C. and at one or two other temperatures at which the resistance fell on the resistance-temperature curve. From these points straight line curves were drawn which show the relation of mil-foot resistance to temperature. In the same way straight line curves were drawn which show the relation of the mass and volume resistivity to temperature. The mil-foot temperature-resistance curves are shown on sheets 13 to 22 and those for the mass and volume resistivity on sheets 23 to 32.

The mass rsistivity in ohms per meter gramme at 0° C. was found from the formula

$$\rho' = \frac{10^4 \, M \, R}{l^2}$$

in which ρ' = mass resistivity, M = mass ~~resistivity~~ of fifty centimeters of sample in grammes, R = resistance of sample in ohms at 0° C. and l = the length of the wire in centimeters.

The volume resistivity in michroms per cubic centimeter at 0° C. was found from the formula

$$\rho = \frac{\rho' \times 10^2}{d}$$

where ρ is the volume resistivity at 0° C. and d is the density.

The density, d, of each sample was found by weighing it in and out of distilled water by means of an accurate chemical balance.

The diameters of the samples were found by means of micrometer calipers. Measurements were taken at several points along the wire, twice at each point, one reading being taken when the micrometer caliper was at right angles to the position when the first reading was taken. The diameter was

then taken as the average of all the readings.

In order to find out whether the samples of copper were hard drawn or annealed tests were made to find the tensile strength.

Data were secured as to the chemical composition and purity of all the copper samples except sample 1 as follows:

Sample	% Copper	% Tin
3	99.49	.3
4	99.	.47
5	99.18	.29
6	99.1	.52
9	98.41	.71
10	99.64	.28

In the above samples the tin appeared only as a coating which would not affect the value of the temperature coefficient or resistivity, the per cent being so small. Sample 1 had no such tin coating.

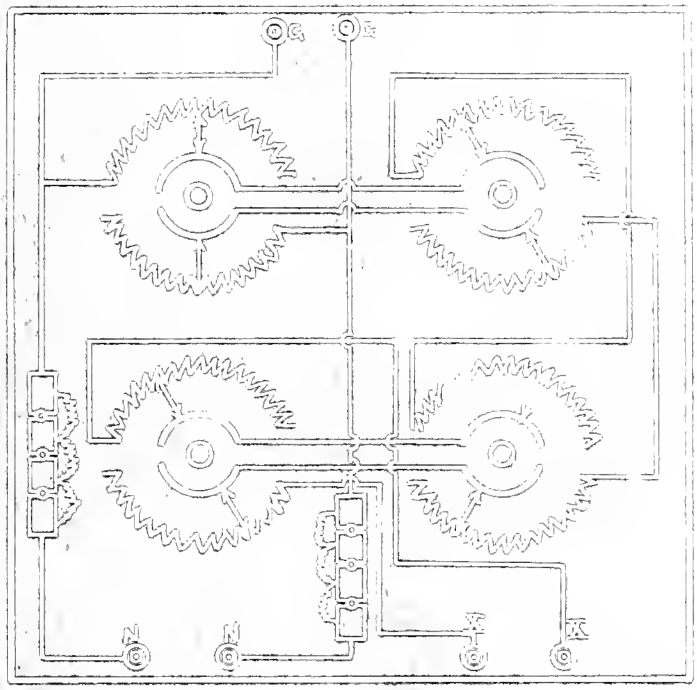
The average temperature coefficient for all the copper samples is .004221, ~~and~~ the maximum value being .004288 and the minimum, .004123. Any slight difference in the purity or treatment of copper will affect its temperature coefficient. The value for the temperature coefficient adopted in the A.I.E.E. Standerdization Rules is .0042; the German rules adpot .004, while on the other hand the British Engineering Standards Committee use .00428. The value of the coefficient, .004221, corresponds very nearly to that of the A.I.E.E. Standardization Rules.

The variation of the temperature coefficient for the steel

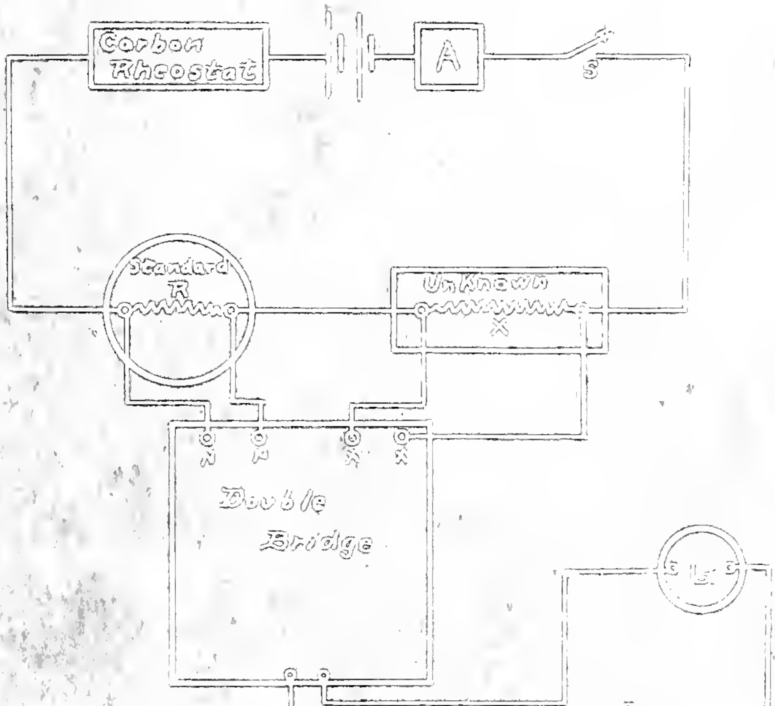
wire is probably due to the different chemical composition and treatment of the samples; however no data as to their purity were obtainable.

The average value of the temperature coefficient, .004455, for aluminium seems to be rather high compared to the value .00435 obtained by Dewar and Fleming for annealed aluminium. Since the purer the metal the greater the temperature coefficient, this would indicate that the sample tested was fairly pure, probably about 99.75% or 99.8% pure. It is also the case that the purer the matal the less the resistivity. It has been determined that the volume rsistivity at 0° C. in michrohms per cubic centimeter for annealed aluminium, 99.66% pure is 2.4322. Since the value obtained here, i.e. 2.421, is lower, this would seem to verify the above estimate as to the ~~the~~ purity of the sample of aluminium tested.

Scheme of Connections of Thompson Duble Bridge



Scheme of Connections for Test.



Sample I Aluminium Wire.

#10 B.W.G.

Temperature C°	Resistance of 50 cm	Temperature C°	Resistance of 50 cm
0.0	.001331	51.51	..001627
5.4	.0013455	56.15	.001650
10.5	.0013755	62.22	.0016865
17.85	.0014255	66.19	.001705
20.93	.001445	70.88	.0017355
26.21	.0014655	76.45	.001766
30.85	.0015030	80.36	.0017905
40.77	.001560	86.00	.001825
46.26	.0015925	91.92	.001856
		96.64	.001883
		101.72	.0019155

Diameter .13808"

Sample 11 Aluminium Wire.

#10 B.W.G.

Temperature C°	Resistance of 50 cm
0.0	.0013105
5.6	.001340
10.5	.0013755
14.7	.0014005
20.55	.001435
25.71	.001467
30.72	.0014995
35.90	.0015315
41.71	.001567
45.44	.0015885
50.40	.0016165

Diameter .13808 inches.

Sample 1 Annealed Copper Wire.

[illegible] B. & S. Gauge.

Temperature C°	Resistance of 50 cm	Temperature C°	Resistance of 50 cm
0.0	.0015[illegible]	50.1[illegible]	.001[illegible]40
17.0[illegible]	.0016[illegible]	[illegible]	.001[illegible]
19.	.0016[illegible]	[illegible]	.001[illegible]
[illegible]	.00164[illegible]	[illegible]4	.001[illegible]
[illegible].07	.0016[illegible]	66.[illegible]4	.001[illegible]
[illegible].06	.001[illegible]61	[illegible]	.001[illegible]
[illegible]4.1[illegible]	.0016[illegible]	[illegible]4.[illegible]4	[illegible]
[illegible]	.0016[illegible]	[illegible]	.001[illegible]1
[illegible]	.001[illegible]	[illegible]	[illegible]
[illegible]	.0017[illegible]	[illegible]	[illegible]
[illegible]4.1[illegible]	.001[illegible]	[illegible]6.[illegible]	[illegible]
[illegible].06	.001[illegible]	[illegible]	[illegible]
4[illegible]	[illegible]	[illegible]4	[illegible]
4[illegible]	[illegible]	[illegible]	[illegible]

Diameter [illegible] inches.

Sample 7 Annealed Copper Wire.

#14 B & S Gauge.

Temperature C°	Resistance of 50 cm	Temperature C°	Resistance of 50 cm
0.0	.00[illegible]	46.50	.00471[illegible]
[illegible].5[illegible]	.0040[illegible]	4[illegible].[illegible]	.0047[illegible]
18.4	.0045475	60.35	.0049[illegible]
1[illegible].74	.0045[illegible]	64.[illegible]	.005015
20.075	.004[illegible]4[illegible]	[illegible].[illegible]	.0051[illegible]
2[illegible].[illegible]4	.004[illegible]	[illegible].57	.005[illegible]
30.105	.004[illegible]	[illegible]0.6[illegible]	.005290
[illegible]4.41	.00[illegible]514	[illegible]1.5[illegible]	.0054[illegible]
[illegible]0.0[illegible]	.0045[illegible]	100.6[illegible]	.005[illegible]

Diameter .06[illegible] inches

Sample 4 Annealed Copper Wire.

" B&S Gauge.

Temperature C°	Resistance of 50 cm	Temperature C°	Resistance of 50 cm
0.0	.003790	57.64	.004660
[illegible].15	.00[illegible]910	60.05	.0047[illegible]
[illegible]0.0[illegible]	.004098	64.50	.004[illegible]00
[illegible]5.76	.004168	70.75	.004[illegible]
[illegible]0.[illegible]	.004255	76.[illegible]	.004[illegible]1
[illegible]5.0[illegible]	.004355	80.75	.00506[illegible]
40.15	.004400	86.04	.0051[illegible]
[illegible]6.60	.004584	90.50	.0052[illegible]
55.70	.004650	96.[illegible]	.0053[illegible]
		100.2[illegible]	.0053[illegible]

Diameter .0054[illegible] inches

15.

Sample 5 Annealed Copper Wire.

#14 B & S Gauge.

Temperature C°	Resistance of 50 cm	Temperature C°	Resistance of 50 cm
0.0	.004080	58.43	.005009
10.[illegible]	.0041055	60.90	.005076
15.80	.004[illegible]	65.[illegible]5	.0051[illegible]6
19.9[illegible]	.004[illegible]66	70.[illegible]5	.005[illegible]41
20.85	.004[illegible]	75.[illegible]	.005[illegible]4
26.[illegible]0	.004[illegible]	[illegible]0.84	.005[illegible]
30.7[illegible]	.004540	[illegible]5.[illegible]	.005[illegible]
37.14	.004[illegible]	[illegible]1.60	.0055[illegible]
40.97	.004[illegible]	96.07	.005[illegible]70
45.16	.004[illegible]5	100.01	.005[illegible]
50.75	.004[illegible]65		

Diameter .06[illegible] inches.

Sample 6 Annealed Copper Wire.

#14 B & S Gauge.

Temperature C^0	Resistance of 50 cm	Temperature C^0	Resistance of 50 cm
0.0	.004[illegible]	[illegible]	.00[illegible]
[illegible]	.004[illegible]	[illegible]	.00[illegible]
[illegible]	.004[illegible]	[illegible]	.00[illegible]
[illegible]	.004[illegible]	60.[illegible]	.005[illegible]
10.1[illegible]	.004[illegible]	[illegible].81	.005[illegible]
11.61	.004[illegible]	[illegible]	.005[illegible]46
1[illegible]	.00441[illegible]	[illegible]	.005[illegible]
[illegible]	.0044[illegible]	[illegible]1.1[illegible]	.00548[illegible]
[illegible]	.0045[illegible]	[illegible]	.0055[illegible]
[illegible]	.0045[illegible]	[illegible]	.00564[illegible]
[illegible]	.004[illegible]	100.[illegible]	.005[illegible]
40.5[illegible]	.0047[illegible]		

Diameter .06[illegible] inches

Sample 9 Annealed Copper Wire.

#10 B & S Gauge.

Temperature C°	Resistance of 50 cm	Temperature C°	Resistance of 50 cm
0.0	.000975	56.61	.001211
10.15	.001014	61.74	.001230
15.55	.001046	65.35	.001244
23.65	.001070	71.11	.001266
27.73	.001092	76.54	.0012905
30.69	.001104	81.65	.001312
35.55	.001124	86.15	.001333
40.78	.001143	90.30	.001350
45.07	.001165	95.75	.001370
50.2	.001185	100.75	.001387

Diameter .10726 inches.

[illegible]ample 1[illegible] [illegible]nealed Copper [illegible]ire.

[illegible] B & [illegible] Gauge.

Temperature C°	Resistance of 50 cm	Temperature C°	Resistance of 50 cm
0.[illegible]	.0012165	51.[illegible]	..0014[illegible]15
4.6[illegible]	.0012[illegible]	51.[illegible]	.0014[illegible]1
[illegible]	.001[illegible]6[illegible]	[illegible].04	.0015[illegible]
15.[illegible]	.0012[illegible]	60.6[illegible]	.0015[illegible]
17.65	.001[illegible]	65.[illegible]	.0015[illegible]05
1[illegible].[illegible]	.001[illegible]05	[illegible].1[illegible]	.0015[illegible]
[illegible].16	.0013[illegible]	[illegible]	.0016[illegible]
[illegible]	.0013[illegible]	[illegible]	.0016[illegible]
[illegible].00	.0013[illegible]	[illegible]	.0016[illegible]
[illegible]	.0014[illegible]	[illegible]	.0016[illegible]
40.[illegible]4	.0014[illegible]7	[illegible]	.001[illegible]
47.[illegible]	.001464	100.05	.001[illegible]

Diameter .11[illegible] inches.

Sample [illegible] [illegible]rican Steel & Wire Co's Extra B.B. Steel Wire,

[illegible] B. [illegible]C.

Temperature C°	Resistance of 50 cm.	Temperature C°	Resistance of 50 cm.
0.0	.0034[illegible]	5[illegible].6[illegible]	.004546
[illegible].[illegible]75	.0035675	60.5[illegible]	.004[illegible]
17.55	.003674	65.[illegible]	.004[illegible]
20.87	.003[illegible]	[illegible]1.0[illegible]	.004[illegible]47
27.86	.004008	76.61	.004[illegible]75
30.06	.004057	[illegible]1.[illegible]6	.005081
36.56	.00410[illegible]	[illegible]6.44	.00510[illegible]
40.82	.004[illegible]64	[illegible]1.13	.005[illegible]
46.30	.004[illegible]	[illegible]5.[illegible]	.005415
51.47	.004410	10[illegible].	.0055[illegible]

Diameter .16[illegible] inches.

Sample 7 Roebling's B.B. Steel Wire.

[illegible] B. [illegible].G.

Temperature C°	Resistance of 50 cm	Temperature C°	Resistance of 50 cm
00.0	.004186	60.48	.005[illegible]1
10.4[illegible]	.004601	66.[illegible]7	.005[illegible]61
1[illegible].[illegible]4	.004[illegible]	70.56	.005[illegible]77
26.1[illegible]	.005066	[illegible]1.[illegible]	.0061[illegible]
[illegible].[illegible]1	.00515[illegible]	[illegible]5.[illegible]	.006[illegible]96
36.04	.005[illegible]	[illegible]1.71	.0064[illegible]1
41.[illegible]	.005[illegible]4	[illegible]6.[illegible]	.0065[illegible]
46.35	.0054[illegible]	1[illegible].[illegible]	.0066[illegible]
51.[illegible]	.005[illegible]4	[illegible]6.10	.0060[illegible]
56.[illegible]	.005680		

Diameter .16[illegible] inches.

Sample 8 Roebling's Extra B.B. Steel Wire.

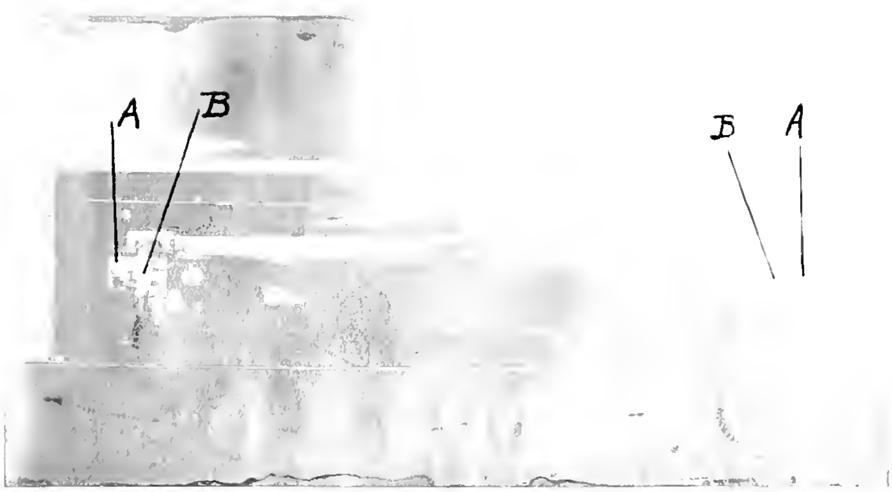
#8 B.W.G.

Temperature C°	Resistance of 50 c	Temperature C°	Resistance of 50 cm
0.0	.004624	60.27	.005874
12.75	.004927	66.75	.005977
19.52	.005008	70.99	.0060275
27.56	.0052015	76.22	.006130
30.57	.005278	81.61	.006316
36.32	.005387	86.40	.006421
41.32	.005471	91.51	.006527
46.71	.005581	101.05	.006738
50.80	.005652	96.71	.006646
55.85	.005756		

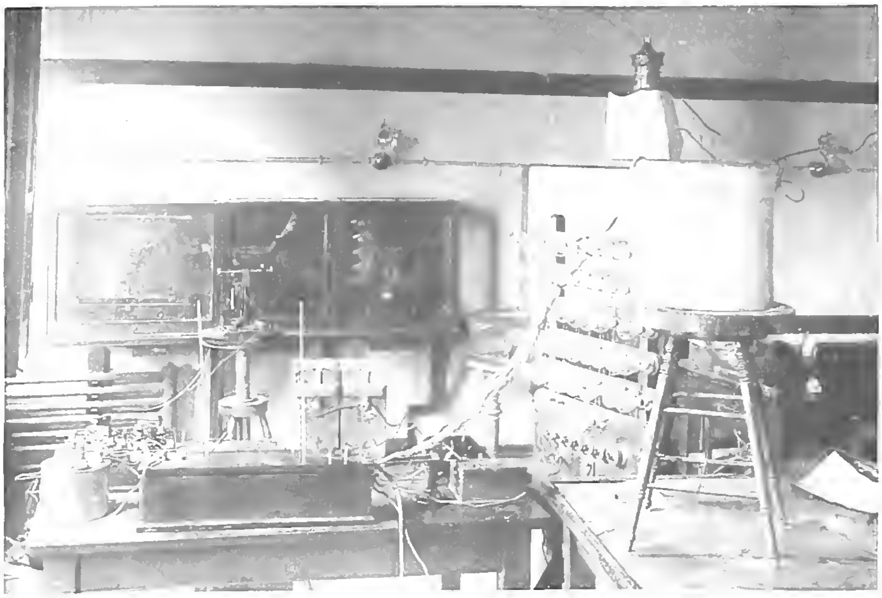
Diameter .1657 inches.

Kind of Wire.	Mean Temperature Coefficient 0–100°C.	Mil-Foot Resistance at 0° C	Mass Resistivity ohms per Meter Gram 0°	Volume Resistivity Microhms per Cubic Cm. 0°	Density $H_2O = 1$	Breaking Load Pounds.
Sample 1. Annealed Copper	.004256	9.618	.1436	1.592	9.0214	290.
Sample 3. Annealed Copper	.004288	10.59	.1431	1.605	8.92	117.5
Sample 4. Annealed Copper	.004227	9.914	.1449	1.6575	8.8443	125.7
Sample 5. Annealed Copper	.004125	9.809	.1444	1.620	8.910	117.9
Sample 6. Annealed Copper	.00418[illegible]	9.816	.1441	[illegible]	[illegible]	[illegible]
Sample [illegible] Annealed Copper	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Sample [illegible] Annealed Copper	.004251	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
[illegible]	.004[illegible]	[illegible]	[illegible]	[illegible]		
[illegible]	.004[illegible]	[illegible]	[illegible]			
Sample [illegible] Aluminum	.004[illegible]					
Sample [illegible] Aluminum	.004[illegible]					
[illegible] Average.	.004427	15.45	.06549	[illegible]	[illegible]	

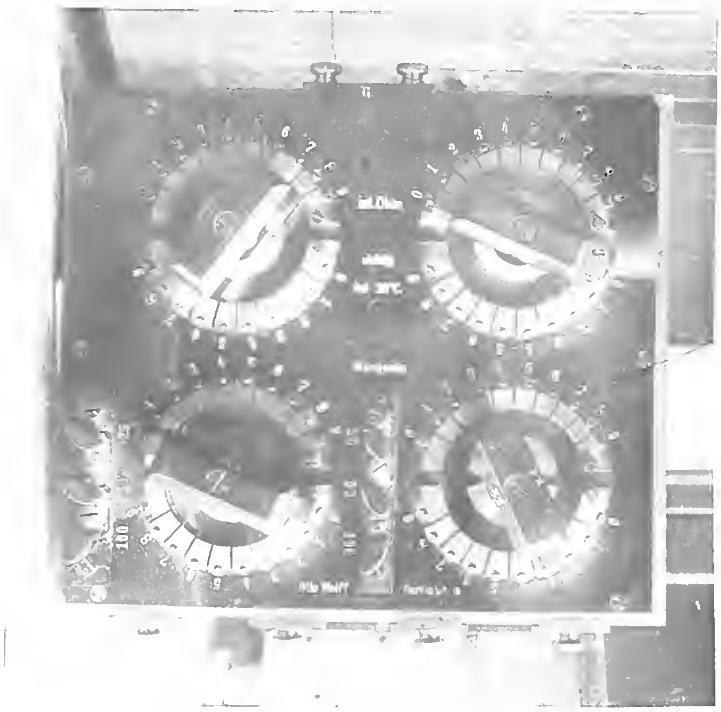
Heating Box.



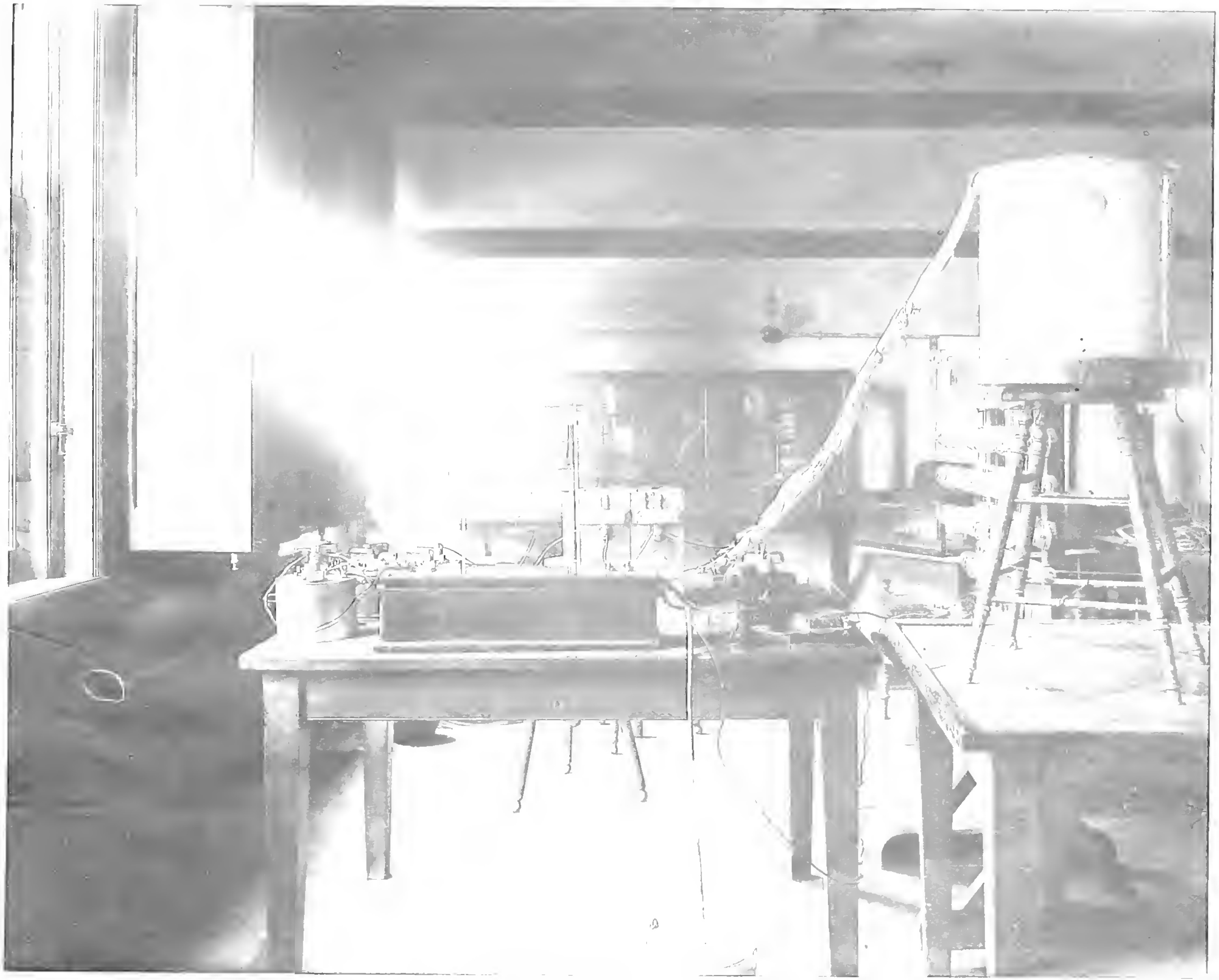
View of Cover of Heating Box showing Knife Contacts.



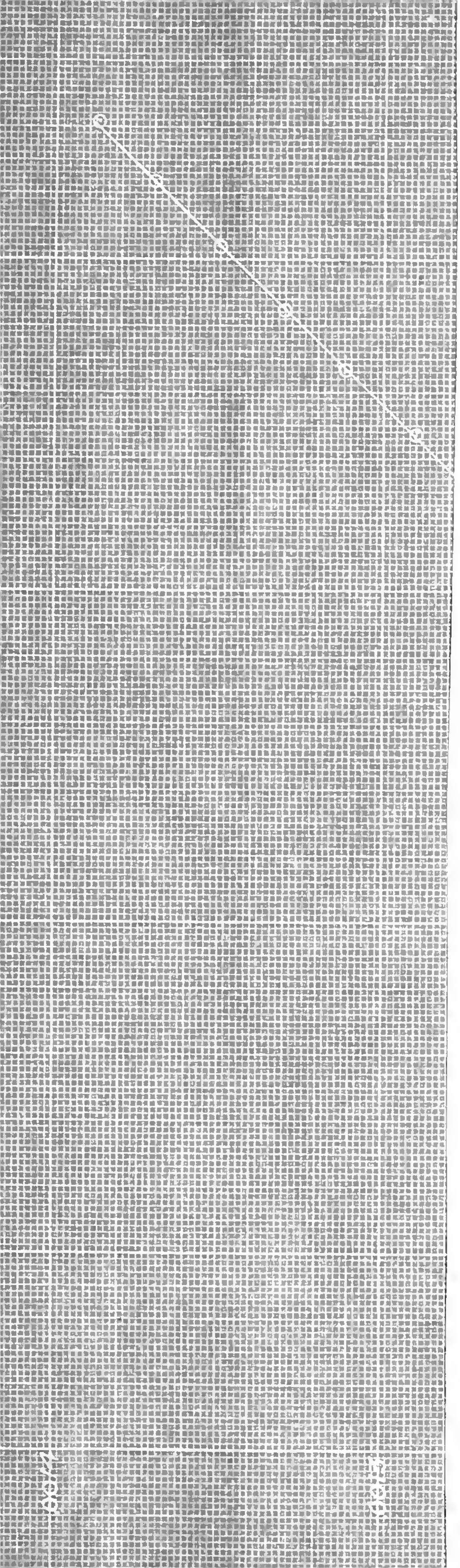
Arrangement of Apparatus.

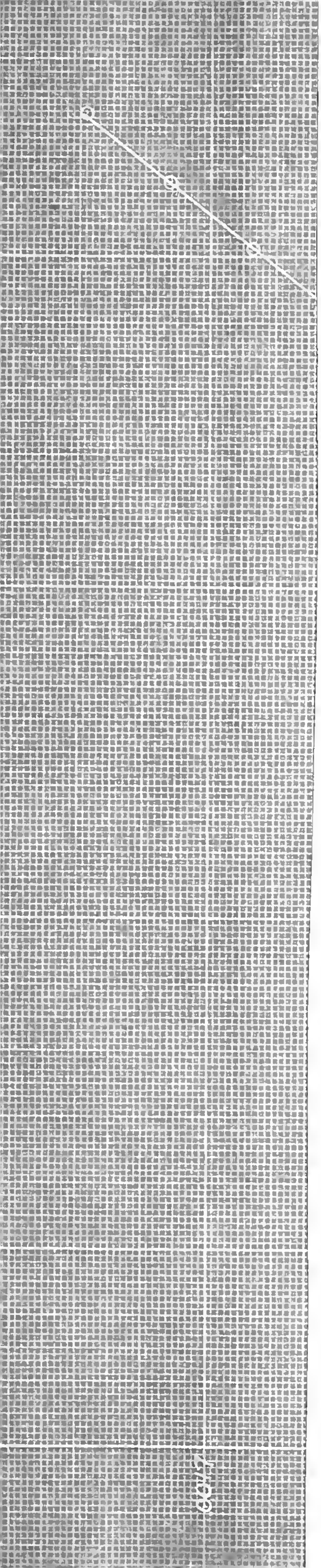


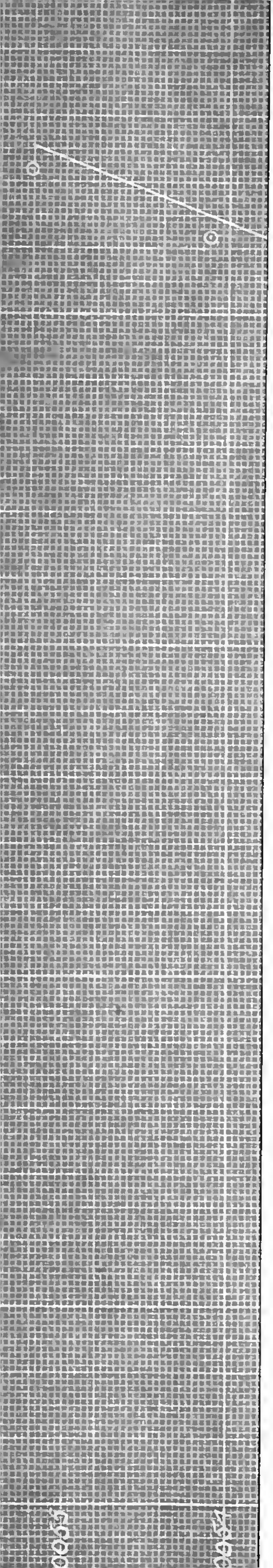
View showing Dials and Ratio Plugs of Thomson Double Bridge.

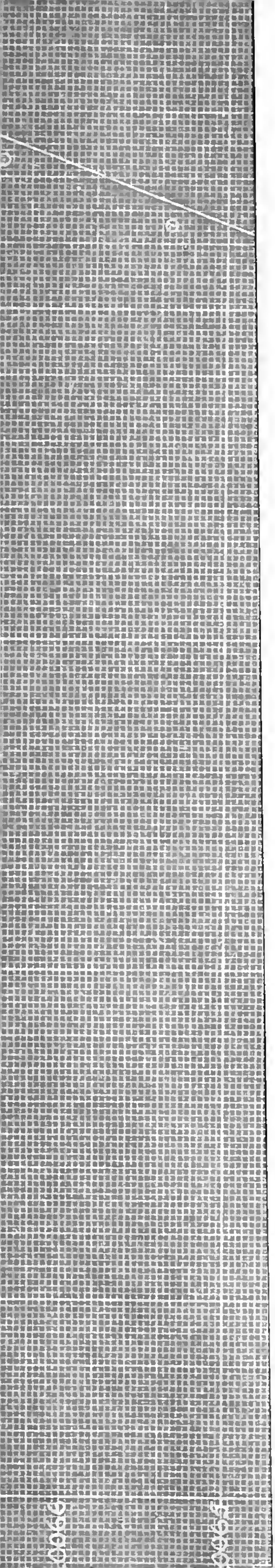


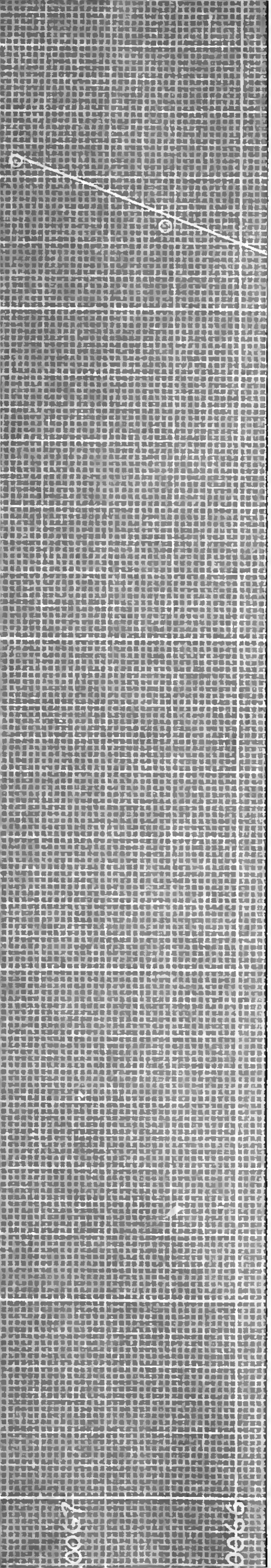
Arrangement of Apparatus.











[illegible]

[illegible]

4.7.